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Verification of Spectral Purity in the HIFI Local Oscillator

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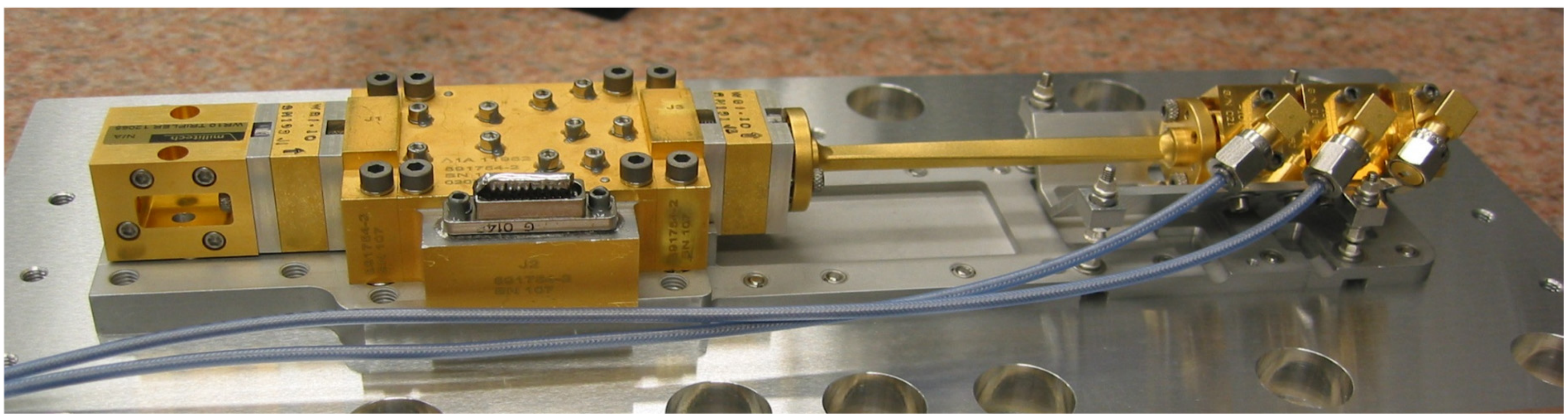
HIFI LO Configuration

- HIFI Local Oscillator
  - RF generated by synthesizer ~7-11 GHz multiplied by 4
  - Waveguide distribution to high frequency components (see below)
  - Control of amplifier drains (input and output stages) and gates (input and output)
  - Bias control on M1 & M2 in band 5 (maximum of 3 bias applied)



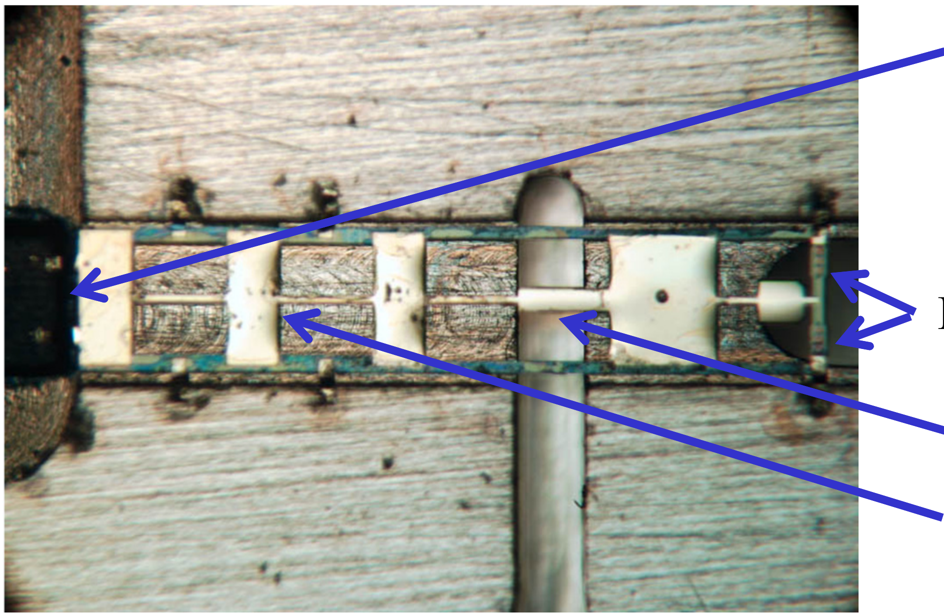
Band 5 LO chain, input tripler, isolator, power amplifier, isolator, x2, x2, x3

Spurs and Spurious Response

- Varactor multipliers have a long history of undesirable behavior.
  - Parametric oscillations occur as a function of frequency, bias, and RF power.
  - They can be strongly affected by impedance of subsequent stage.
  - The oscillations can generate strong spurs and even dominant spurious frequencies.
- No design guidance in the literature
  - Not even complete agreement on the origins of the oscillations.
  - Higher efficiency generally results in more problems.
- HIFI Local Oscillator design focused on performance and did not consider parametric oscillations.
  - Oscillations of various severity found after the fact:
    - Band 1a x2x3
    - Band 2b x2x2x2
    - Band 3b x2x2x3
    - Band 5a & b x2x2x3
    - Band 7a & b x2x3x3
  - All involve doublers in either the first or second stage multipliers.

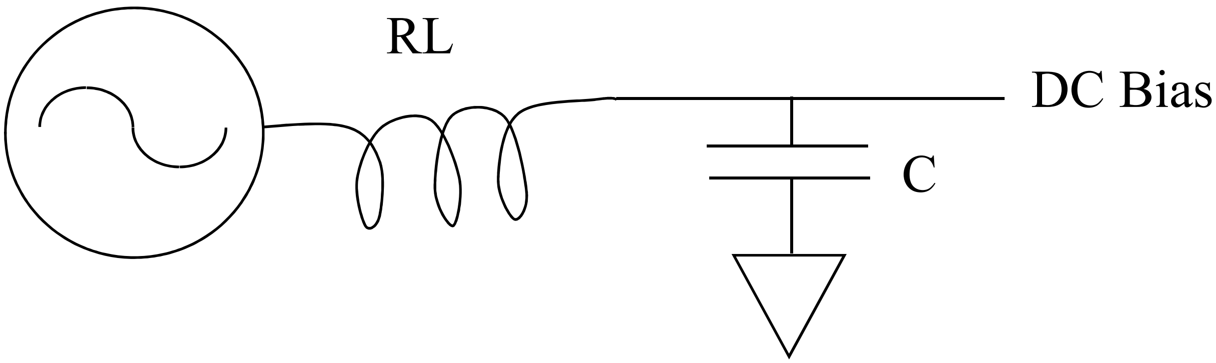
Origins of Oscillation

- HIFI doublers have all similar designs
  - Balanced symmetric configuration with devices in input waveguide
  - Bias and RF output go through output waveguide
    - Current at twice the RF frequency terminated in bias capacitor
    - Capacitor can be either on chip or separately mounted



Doubler Oscillation Mechanism

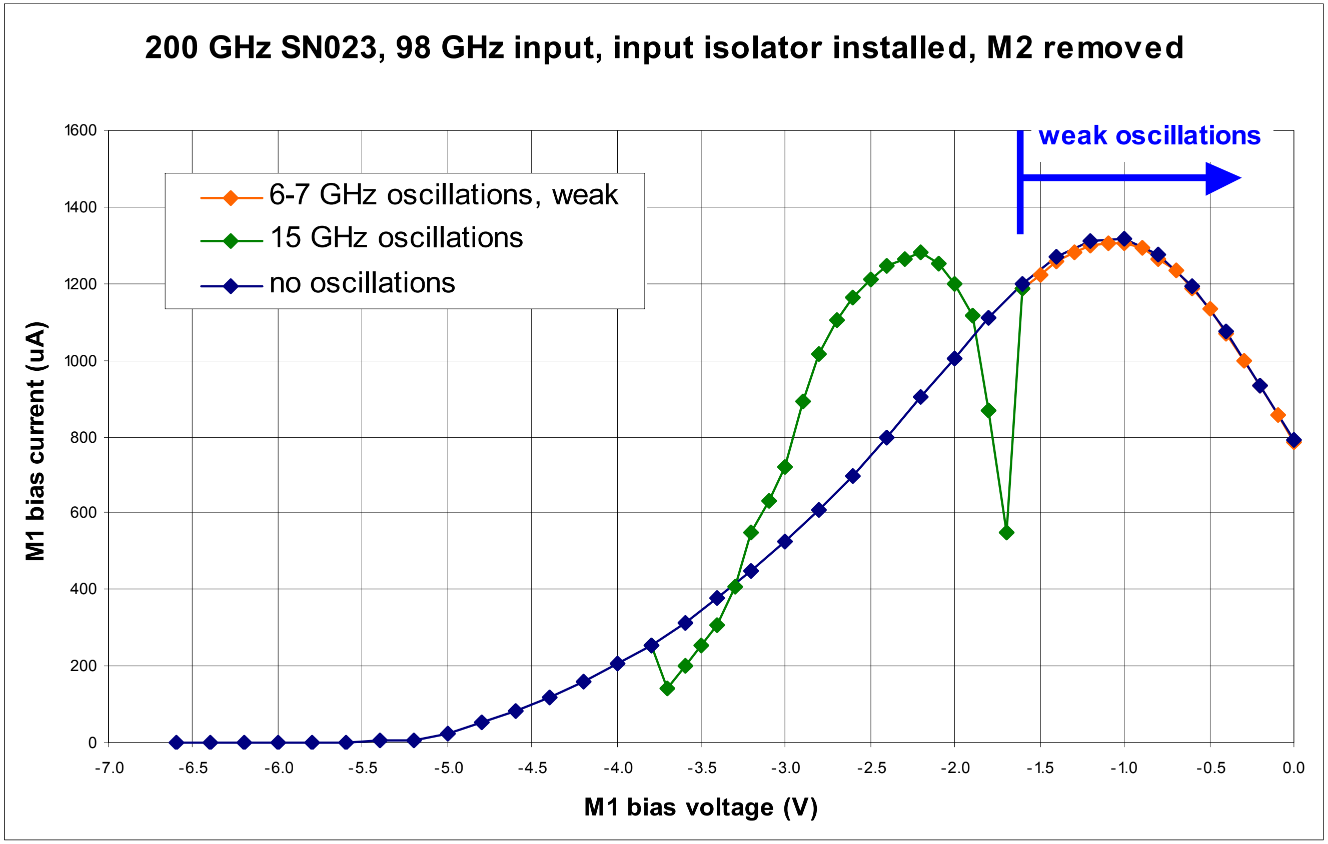
- Diode pumps charge at twice the input frequency.
- Bias circuit can be approximated by an LC (real circuit is much more complex).



- The electrical analogue is a small pendulum attached weakly to a large one.

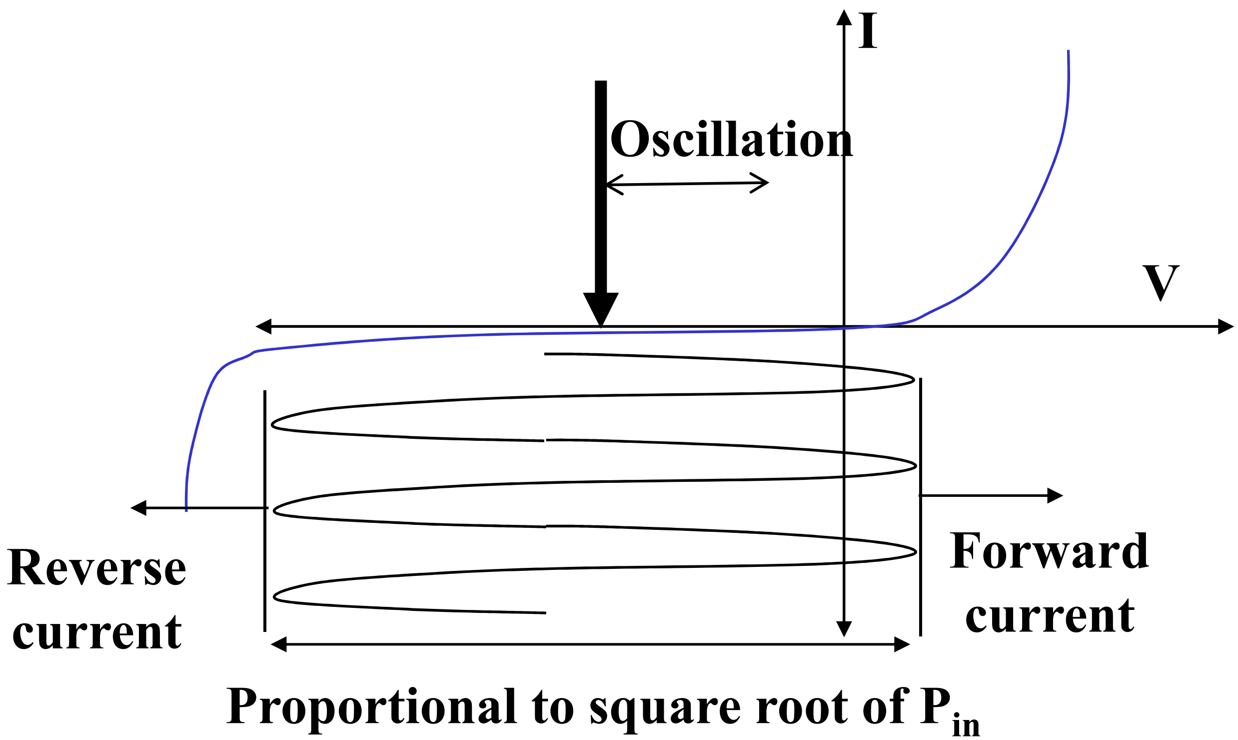
- If nxLC is ~twice the input frequency it can oscillate, the **details of the phase shift** determines the exact frequency.
- LC is not high Q so bandwidth is significant
- Oscillation is “forced” and maintains the spectral purity of input frequency.
- Oscillations modulate the bias point.
- Gain obtained by differential pumping of charge. The gain can be high.
- **All varactor doublers** of this design can have this effect.

IV curve of Doubler



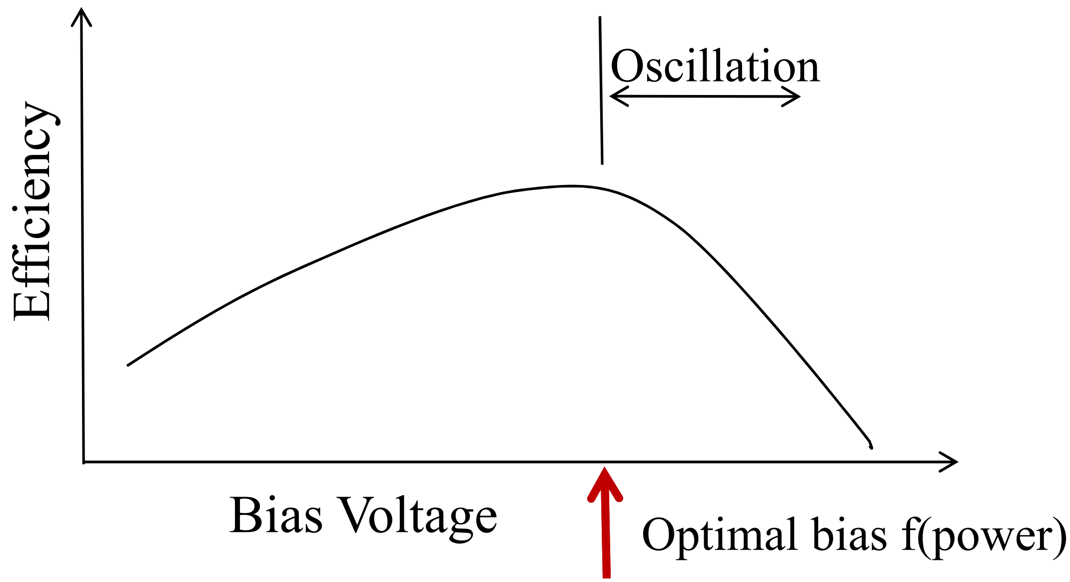
Different modes of multiplier: blue nominal, green oscillating, and orange with weak spurs. Any oscillation modulates the bias point and its averaged waveform causes the blue line to shift to the green curve. This effect generates AM sidebands on the carrier.

IV curves and RF Waveforms



The shifting bias point moves RF swing to the left or right, thus changing both forward and reverse currents.
The RF swing is not linear, symmetric or constant with frequency.

Sideband Generation

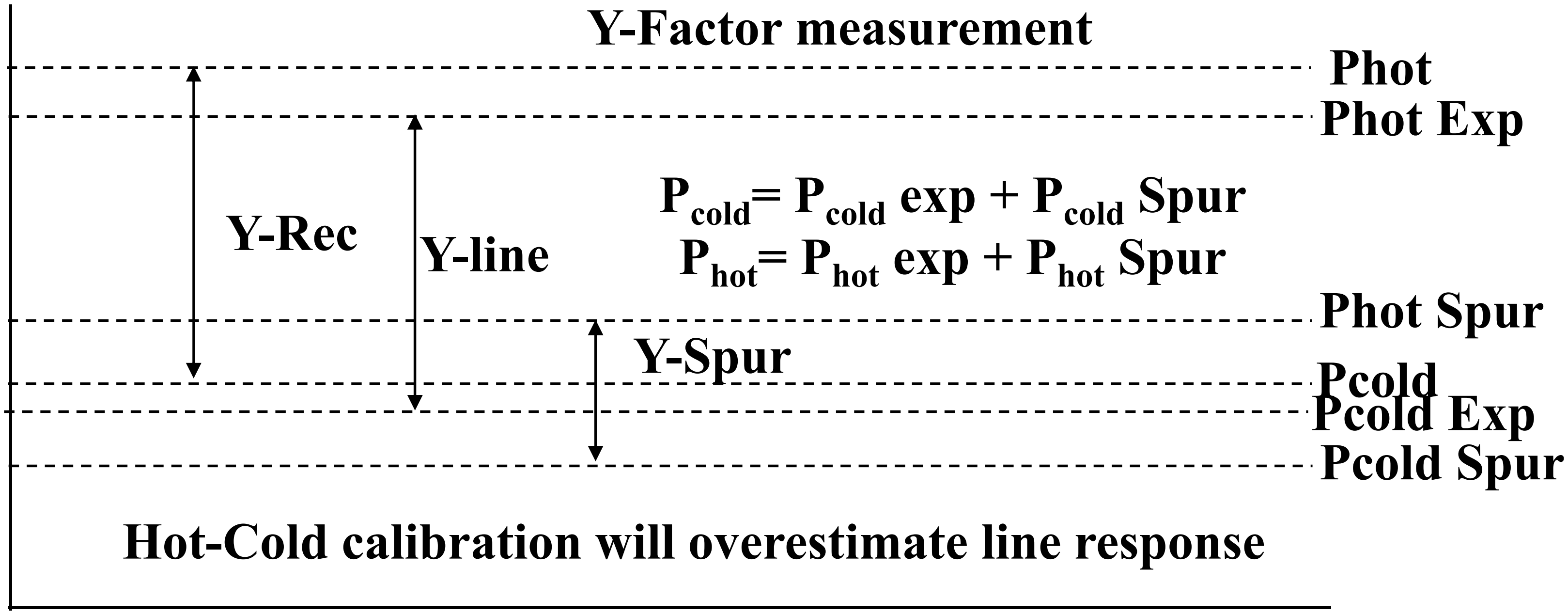


- Each power level generates similar curve. The optimal bias point moves slowly away from zero as RF power increases.
- Bias is generally set for maximum power. Oscillations can produce a false impression that the efficiency is higher at low RF drive level. This effect is not as pronounced at high power level.
- Oscillation introduces AM sidebands at the bias modulation frequency. Its modulation depth can approach 100%.

Spurious Response

- AM modulation can approach 100%
  - Frequency is approximately the LC product (within resonance envelop)
  - In HIFI these frequencies are all between 13-23 GHz
    - First stage multipliers have oscillations around 15 GHz
    - Second state multipliers have oscillations around 20 GHz (caused by smaller L)
- AM sidebands are converted at least as 20 Log(N) (mixed not multiplied)
- When conversion efficiency is much higher on one side band or the other then one tone can become larger than the carrier.
  - Edges of bands are particularly vulnerable to this problem
  - Oscillations earlier in cascade of multipliers have larger effects
- Strong spurs are generally indication of problems
  - There are many combinations to intermodulate with multiples of the fundamental frequency.
  - HIFI doesn't detect the direct sideband in the IF. (FWM: what is this?)

The Problem: Actual Gain?



Extra tone(s) effectively change the sideband response i.e. two equal tones in each sideband would be 25% of the total response. The expected result would be 50% when applying a calibration.

The fraction is not easily determinable from an observation unless T_A^* is known *a priori.*

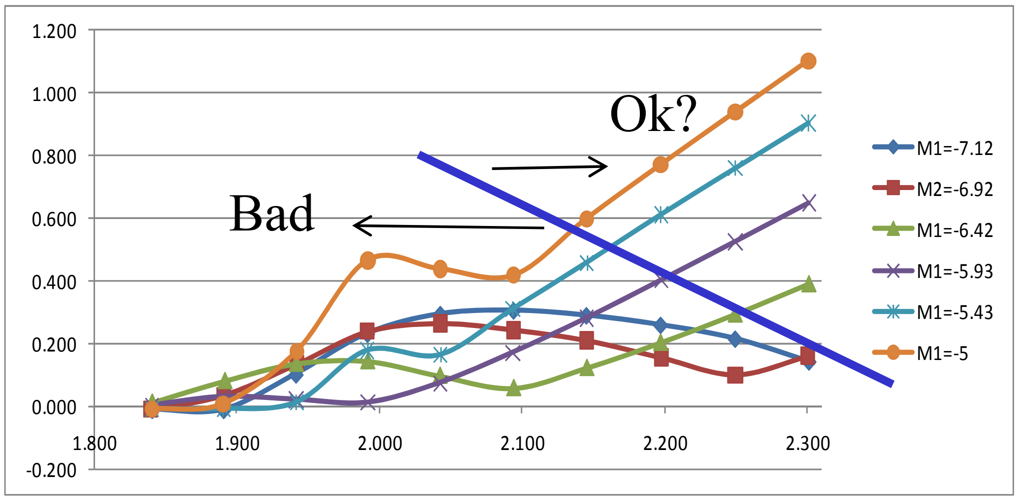
Standard calibration schemes will greatly overestimate the response to expected frequency. The result is corrupt science data.

Identification of Oscillations

- In the design stage a bias-T is the best approach to detect oscillations with a spectrum analyzer.
  - Should be performed with initial testing and again once the multipliers are cascaded.
  - One mitigation is to change capacitance or inductance.
  - New design if all on chip (unless dielectric can be altered in capacitor).
- Detection with a spectra of gas cell or astronomical source is possible
  - Use well studied gas where all strong lines are known unexpected lines are problematic
    - Methanol used for HIFI
    - Absorption spectroscopy can be used as well
  - For astronomical sources the LO needs to be changed by a few 100 MHz
    - Plot upper and lower sideband pictures for multiple steps
      - If the expected lines are not in either sideband then this is sign of oscillation
      - Large flux changes are also sign of oscillation
- Calibrated diplexer can be used as Fourier transform spectrometer
- In IV curves
  - Measure multiplier IV curve at fixed bias as a function of RF input power
  - Current should be an increasing function of RF (unless very far from optimal bias)

IV Curve Method 1/2

- In HIFI several bands 1, 2 & 5 have beam splitters
  - No easy handle on spectral purity
  - Known problems in band 5
  - Problems found in band 1 and 2
- Parameterize bias in steps around the optimal point
  - If nominal is -7V use -6V, -6.5V, -7V, -7.5V and -8V
  - Take care not to reverse breakdown multiplier
- Ramp RF usually highest power to lowest power
  - Plot multiplier current vs RF power



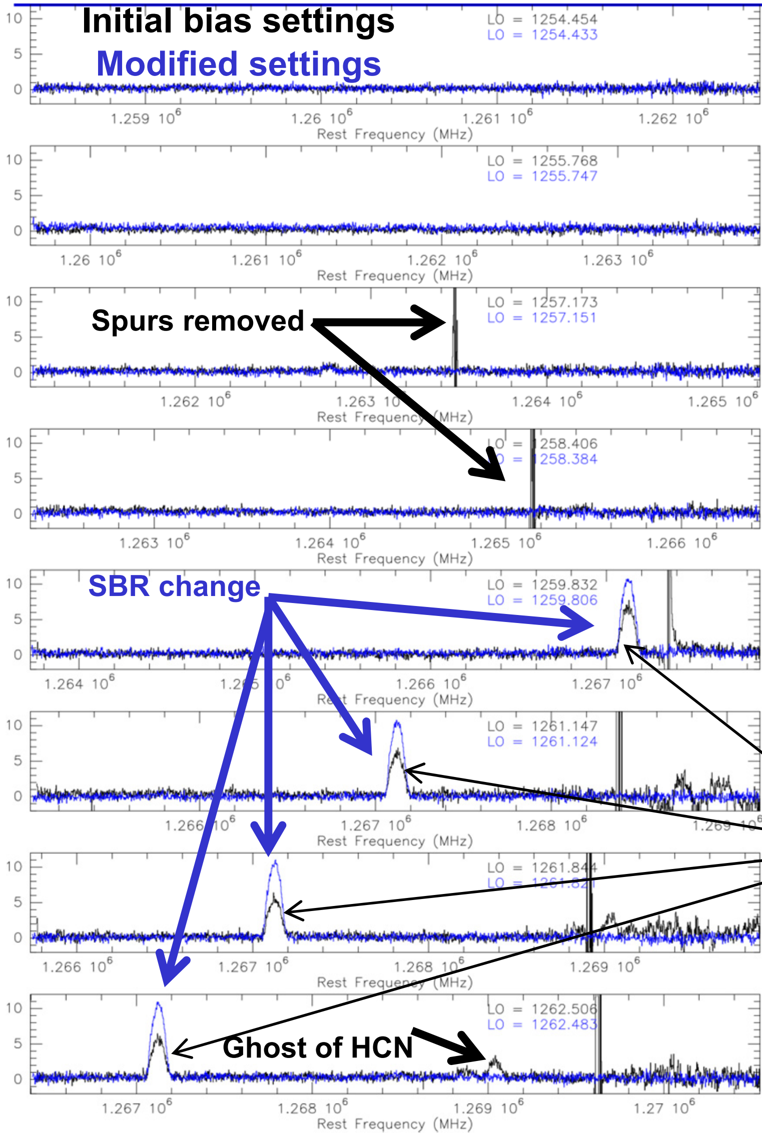
IV curves at 1246 GHz
Nearly nominal at maximum RF drive level

X-axis is saturated amplifier drain voltage (RF level)

IV Curve Method 2/2

- The challenge is to pump mixer with sufficient RF power and get rid of oscillation
  - Low input power generally does not help
  - More forward bias reduces efficiency and forces more varistor mode
  - More reverse bias can lead to pure varactor mode
    - Oscillation requires forward current of usually >1uA

Results of changes in band 5b



Spurs vanished from spectrum

Intensity of lines changed dramatically

Ghost lines were removed

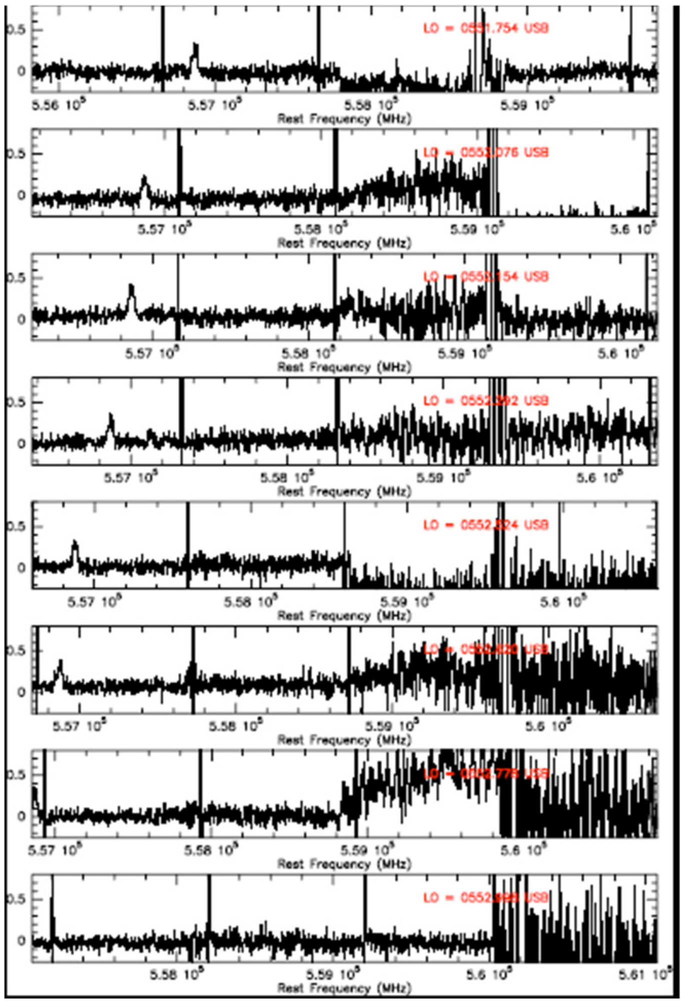
SBR changes because extra tones from oscillation were removed

May 2010

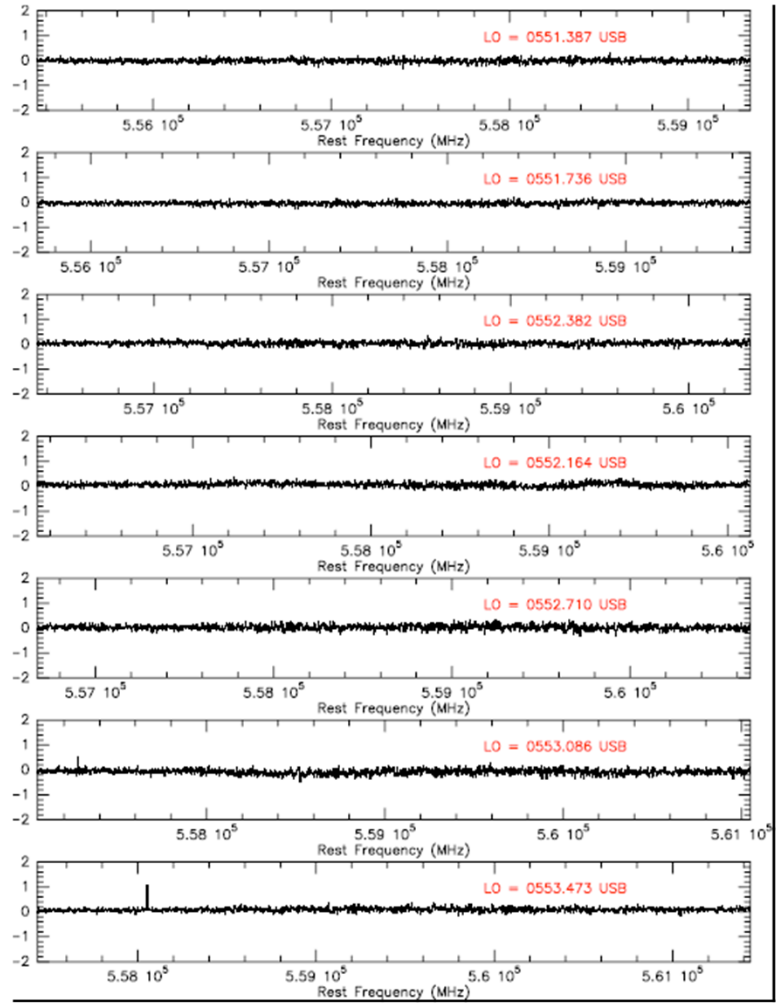
Nov. 2010

CO Line expected at this frequency
New settings recovered flux lost to other tones in mixer

Results of Corrective Action



Band 1a Oscillating Spur saturates spectrometer



Band 1a fixed no more strong spurs

Conclusions

- Most of the oscillations where suppressed by modification of the operating condition of the multiplier chain.
  - Change in RF power level from the power amplifier.
  - Change of bias point of the multiplier bias.
  - Iterate to achieve desired pump level and required spectral purity
- All HIFI bands are working properly
  - A few 1-2 GHz windows were not corrected see observers manual
- Further study has to be performed in order to develop design criteria like the amplifier K-factor analysis to minimize the possibility of parametric oscillations
  - The bias circuit is critical in the balanced doubler design

Acknowledgement

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Backup

Spurious Test

- For regions where spurious response is possible the following can be done
  1. Display data in both upper and lower sideband representation for all LO settings
  2. Verify the TA does not vary significantly (>10%) on strong lines in bad region
  3. If it does scale entire spectrum to agree with the last unaffected region
  4. Work way through bad region scaling each from both sides
  5. Check other side band representation
  6. Spurious response will not agree in either representation treat any obvious lines from the spurious response like a spur i.e. take it out
  7. Then do the deconvolution it will treat the spurious response like noise
- For single observations stay out, use the other sideband if necessary

Definitions

- Spurs
  - Coherent (or nearly coherent) signals observed in the IF
  - Effects
    - A few frequency pixels to an entire WBS sub-band are lost or impossible to calibrate
  - Cause
    - Can be harmonically related to LO, internally generated, or picked up
- Spurious Response
  - Receiver responds at one or more unexpected frequencies
  - Effects
    - Some to most of receiver response is not at the desired frequency
    - Intermodulation in mixer and/or LO
    - Incorrect calibration on any observed line
  - Causes
    - Strong harmonic in LO chain
    - Oscillation in LO chain